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Soil Disturbance-Tree Growth Relations in Central Idaho Clearcuts

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ABSTRACT

Two central Idaho clearcuts regenerated naturally to lodgepole pine (Pinus contorta) *and one regenerated with planted ponderosa pine* (Pinus ponderosa) *were evaluated to see if soil compaction and displacement affected growth as measured by tree height, diameter at breast height, and radial growth increment. Pole-sized trees ranging in age from 15 to 25 years occupy the sites, and soils contain considerable volcanic ash in the surface 30 cm. Significant (90 percent level) declines in one or more growth attributes were associated with increased penetration resistance and lateral soil displacement at all three sites. One site had significant (99 percent level) growth declines associated with increased soil bulk density. Results of these studies suggest that steps to minimize lateral soil displacement and compaction are required to maintain potential productivity levels on these soils.*

KEYWORDS: soil compaction, growth declines, lodgepole pine, ponderosa pine

Yarding logs with ground skidders, either crawler tractor or rubber-tired skidders, can cause considerable soil disturbance. Megahan (1980) summarized results from 16 logging studies in the United States and Canada and found that the average percentage of area disturbed by ground skidding (excluding roads) is 21 percent, and includes lateral soil displacement, horizon mixing, and compaction. This disturbance affects the soil resource both positively and negatively. Minor displacement or mixing is often cited as beneficial for regeneration because it prepares a seedbed and reduces competing vegetation. On the other hand, soil disturbance reduces soil cover that affords protection from erosion, disrupts soil biological processes important to nutrient cycling, and can change soil physical properties to the detriment of plant production.

Lateral soil displacement can cause localized productivity losses on a site in similar fashion to the more generalized losses resulting from erosion. In addition, accelerated erosion is an almost universal consequence of forest soil disturbance (Gilmour 1977; Hewlett 1979; O'Loughlin and others 1980; Rice and Datzman 1981). The potential productivity loss accompanying soil displacement or erosion in forested ecosystems is poorly understood. For decades soil loss tolerance levels for nonforested agricultural lands have been studied and tolerance levels established, although the soil loss productivity relationship is still not well defined (National Soil Erosion-Soil Productivity Research Planning Committee 1981). Rice and others (1972) point out that soil loss from logging activities rarely occurs uniformly over the logged area and tends to be localized. These authors suggest that much less degradation of site quality is expected than would be the case if erosion were more uniform over the whole surface. Lateral soil displacement also disrupts biological processes that play an important role in terms of (1) soil nutrient levels and availability, (2) decay of woody plant material, and (3) activities of plant pathogens (Jurgensen and others 1979). Timber harvest activities that disturb surface soil may accelerate decomposition and mineralization resulting in increased leaching and nutrient loss. Displacement of organic matter may also adversely affect soil physical properties.

In addition to erosion and surface biological effects, ground skidding may adversely affect soil physical properties by compaction. Forristall and Gessel (1955) in Snohomish County, WA, found that increased bulk density from compaction impeded root growth. Western redcedar (*Thuja plicata*) tolerated densities to 1.8 Mg/m^3, red alder (*Alnus rubra*) to 1.5 Mg/m^3, and Douglas-fir (*Pseudotsuga menziesii*) and western hemlock (*Tsuga heterophylla*) to only 1.3 Mg/m^3. Daddow and Warrington (1983) reviewed results of several published studies and concluded that growth-limiting bulk densities are texture dependent. They suggested that soils with a large amount of fine particles (silt plus clay) will have lower growth-limiting bulk densities than will coarse-textured sandy soils. Their predictions for growth limitations are restricted to soils with less than 10 percent gravel, a severe limitation for many forest soils. In addition, they were unable to make predictions about productivity loss because of the lack of published data relating productivity to compaction. Helms (1983) studied compaction effects on two ponderosa pine stands in California and concluded that bulk density accounted for

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10 to 20 percent of the variability in height growth. Volume production per acre showed a reduction of 20 percent due to compaction for both stands. Wert and Thomas (1981) documented Douglas-fir productivity declines on skid-roads in western Oregon. Volume losses of 12 percent for the entire area were reportedly due to compaction along skid trails, and this caused both lower stand density and reduced volume growth. Froehlich and others (1983) suggest that there is a predictable relationship between percentage decrease in seedling height growth and percentage increase in soil density based on six United States studies.

Published data relating soil disturbance to productivity are unavailable for the Northern Rocky Mountain Province forest lands. Few studies document the extent and longevity of soil compaction caused by logging activities in this area. Froehlich and others (1983) studied compaction along skid trails on soils formed from granitic and volcanic parent materials in central Idaho. They concluded that compaction as measured by increased bulk density is present on both soils, and they predicted effects will last 45 years. They made no evaluation of productivity loss due to compaction.

This paper reports results of a study conducted in the Nez Perce National Forest, north-central Idaho. Three stands, clearcut in the 1960's and yarded with a crawler tractor, were independently evaluated for soil disturbance and tree growth in order to test if productivity is correlated with soil disturbance. Soil disturbance evaluations included measurements of bulk density, resistance to penetration, and lateral soil displacement. Tree growth was measured by tree height, diameter, and radial growth increment. Soils on two of the sites are formed from quartzites, gneisses, and schists of the Belt Supergroup; soils of the third site are formed from basalt of the Grande Ronde formation. All soils have a considerable volcanic ash content in the surface 30 cm. These soils are widespread in northern and north-central Idaho forests and are probably subject to compaction when disturbed.

The objectives of this study were (1) to determine if there are impacts on site productivity as measured by tree growth resulting from the cumulative effects of soil disturbance on a "typical" harvest unit and (2) to develop a practical and inexpensive methodology for monitoring management practices on soil productivity.

SITE DESCRIPTIONS

The Deadwood study site is an 11-ha clearcut located in the S½ sec. 16, T. 28 N., R. 8 E., on the Elk City Ranger District, Nez Perce National Forest. Median elevation is 1,485 m. Slopes range from 0 to 10 percent and have a southwest aspect. The habitat type (Cooper and others 1985) is grand fir/beargrass (*Abies grandis/Xerophyllum tenax*). Mean annual precipitation is 102 cm, most of which falls as snow in the winter. Soils are classified as coarse-loamy, mixed, frigid, Andic Dystrochrepts, and typically have a loam or silt loam surface texture. Soils are formed on metamorphic rocks of the Belt Supergroup, but have a significant volcanic ash content in the surface 30 cm. Soils are deep and well-drained. The site was clearcut in 1969. Crawler tractors were used to log the stand, and slash was broadcast burned in 1970. Engelmann spruce (*Picea engelmannii*) and Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) were planted in 1971, but lodgepole pine (*Pinus contorta*) has regenerated naturally and is the dominant species. The average stand age is 15 years.

The Dawson Creek site is a 7.5-ha clearcut located in the NW¼ sec. 25 and the SW¼ sec. 24, T. 28 N., R. 8 E., on the Red River Ranger District, Nez Perce National Forest. Slopes range from 0 to 10 percent and face southeast at an average elevation of 1,475 m. The habitat type is grand fir/beargrass. Mean annual precipitation is 102 cm. Soils are coarse-loamy, mixed, Eutric Glossoboralfs with a silt loam surface texture, are well-drained and deep, and are formed on metamorphic rock but with volcanic ash in the top 30 cm. The site was clearcut in 1966 and yarded with a crawler tractor, and slash was tractor piled and burned. The stand regenerated naturally to lodgepole pine and was precommercially thinned in 1979. The approximate stand age is 19 years.

The Shell's Lick site is a 20-ha clearcut located in the W½ sec. 6, T. 27 N., R. 3 E., on the Slate Creek Ranger District, Nez Perce National Forest. Slopes range from 0 to 10 percent and face west at an average elevation of 1,730 m. The habitat type is grand fir/beargrass. Mean annual precipitation is 115 cm. Soils are loamy-skeletal, mixed, Andic Cryochrepts with a silt loam or gravelly silt loam surface texture. Soils are well-drained and moderately deep, formed on basalt from the Grande Ronde formation, and contain ash in the top 30 cm. The site was clearcut in 1961 and the logs yarded with a crawler tractor. The exact method of slash disposal is unknown, but was probably a combination of tractor piling, jackpot burning, and broadcast burning. Ponderosa pine (*Pinus ponderosa*) was planted on a 2- by 2-m spacing starting in 1961 and ending in 1964. The current stand is 20 to 25 years old.

METHODS

Field Procedures

Independent estimates of tree growth and soil disturbance were made at each study site in 1984. Sites were characterized as to soil lateral displacement by machinery, soil bulk density, and resistance to penetration in the following manner: All undamaged trees greater than 7.5 cm diameter at breast height (5 cm at Deadwood) constituted the population of plot centers for soil disturbance estimates in each clearcut. For lateral soil displacement, the crown drip line delineated the approximate boundary within which displacement was estimated. Three classes of displacement were considered:

1. None-slight: generally no sign of lateral soil displacement within the crown drip line area; if minor lateral soil displacement occurred, it occurred on less than 25 percent of the area.
2. Moderate: 25 to 49 percent of the crown drip line area has lateral soil displacement, or greater than 25 percent of the area has been laterally displaced, but surface soil is still present on displaced areas.
3. High: 50 percent or more of the area within the crown drip line has been laterally displaced.

Because it had been approximately 20 years since the disturbing activity, evidence for lateral soil displacement was not always readily apparent. We defined displacement as removal of part or all of the surface soil (top 30 cm) that would occur on the plot assuming all plots had a soil profile similar to that on adjacent undisturbed sites. We feel this is reasonable in view of the uniformity of soils on these relatively stable slopes.

At the Deadwood site, three bulk density core samples were taken in each plot at 120-degree intervals around the drip line of each tree. Single cores were taken at each plot at Dawson Creek and Shell's Lick sites. Cores were driven vertically into the soil using a 295-cm^3 coring device having a length of 17 cm and a diameter of 4.7 cm.

Resisiance to penetration was estimated subjectively using a "sharpshooter" soil surveyor's shovel, which is essentially a long-bladed spade. The blade of the shovel was pressed by foot through the surface 17 cm of soil at three locations on each plot in a fashion similar to the coring done at the Deadwood site, taking care to avoid the soil disturbed during coring. The individual doing the penetration tests first sampled several areas that were undisturbed by logging to learn to recognize natural soil conditions, then sampled several skid-road locations to learn to recognize penetration resistance due to compaction. These two subjective measurements constitute our slight and high resistance levels, respectively. Anything in between was given a level of moderate. To test if this procedure in fact had any validity, we independently double sampled another study area with both the sharpshooter shovel and a 30-degree cone penetrometer. Penetration classes determined by shovel of low, medium, and high had penetrometer values (mean $\pm$ standard error) of 685 ± 48, $1{,}110 \pm 49$, and $1{,}705 \pm 49$ kPa, respectively. This suggests that real and consistent differences in penetration resistance can be estimated with a shovel.

Tree Sampling

Plot centers were located in all three stands using a 20- by 20-m square spacing. A starting point was selected randomly, and a square grid was established systematically using cardinal compass directions from the starting point. At each plot center a 2-m radius circular plot was used to determine which trees would be measured. Individual tree measurements were taken using the Forest Service Northern Region's Stand Exam Guidelines (USDA Forest Service 1985). Height was measured to the nearest 3 cm using a measuring rod, and diameters were measured to the nearest 0.25 cm. Every tree over 7.5 cm diameter at breast height (d.b.h.) was bored to determine the age and radial growth increment at breast height. The radial growth was measured for the previous 10 growing seasons and recorded to the nearest 0.1 cm.

Stocking comparisons for the various soil disturbance groupings at Shell's Lick and Deadwood were made using the Northern Region's Basic Stand Tables Edit routine to judge if differences in growth parameters might be due to competition. The mean number of trees per hectare and 95 percent confidence interval by disturbance class (low, medium, high) for each disturbance type (displacement, soil density, penetration resistance) was projected. At Deadwood and Shell's Lick, stocking showed slight declines with increasing disturbance, but all confidence intervals overlapped. Stocking was more uniform at Dawson Creek, which had been precommercially thinned, and again all confidence intervals overlapped. Mean stockings at Deadwood, Shell's Lick, and Dawson are 2,480, 1,037, and 2,200 trees per hectare, respectively. Although stocking is different between sites, there is no reason to suspect stocking differences among disturbance classes within a site contribute to growth differences.

Data Analysis

Soil displacement and penetration resistance classes were tested for effects on radial growth, diameter increment, and tree height using analysis of variance. A least significant difference (LSD) test was run on those groups that tested significant at the 90 percent level. Bulk density effects on growth were tested as a continuous variable using regression analysis. The effects of bulk density and penetration resistance on growth were examined together using covariance analysis with bulk density as a covariate.

RESULTS

The effects of soil displacement and resistance to penetration on d.b.h., radial growth, and height are presented in tables 1 and 2. Lateral soil displacement is associated with decreased d.b.h. at all three sites. Height growth and radial growth are lower on moderately and highly displaced soils at the Deadwood and Shell's Lick sites, but there is no statistical evidence for decreased growth at the Dawson site. Penetration resistance increases are associated with decreased d.b.h. at Deadwood and Dawson Creek but not at Shell's Lick. Height growth at Deadwood and Shell's Lick, and radial growth at Deadwood are lower on soils with moderate or high penetration resistance.

Radial growth, tree height, and d.b.h. exhibit statistically significant (99 percent level) negative correlations with increased soil bulk density at the Deadwood site but not at the other two sites. The following equations describe relationships at Deadwood:

$$\mathrm{RG} = 6.01 - 2.03\ \mathrm{BD};\ n = 28,\quad r^2 = 0.20,\ \mathrm{F} = 7.909^{**} \tag{1}$$

$$\mathrm{HT} = 5.7 - 1.74\ \mathrm{BD};\ n = 28,\quad r^2 = 0.32,\ \mathrm{F} = 13.73^{**} \tag{2}$$

$$\mathrm{d.b.h.} = 9.8 - 3.15\ \mathrm{BD};\ n = 28,\quad r^2 = 0.40,\ \mathrm{F} = 19.18^{**} \tag{3}$$

where

RG = radial growth in cm over the previous 10 years

BD = bulk density in Mg/m^3

HT = tree height in meters

d.b.h. = diameter breast height in cm.

Mean bulk density values for disturbed and undisturbed plots are presented for each study site in table 3. Increased bulk density from soil compaction was slight at Shell's Lick in the surface 17-cm core samples (0.82 to 0.94), but increased penetration resistance was more common. This suggests that a layer of increased soil strength,

Table 1—The effects of soil displacement on diameter at breast height (DBH), radial growth (RG), and tree height. Values are means for each displacement class; means with different letters are significantly different using a least significant difference test at the 10 percent level

Site	Displacement class	DBH	RG	Height	Plots
		cm	*cm/10 yr*	*m*	*Number*
Deadwood (lodgepole pine)	Slight	6.9 a	4.2 a	4.15 a	15
	Moderate	5.8 ab	3.3 ab	3.60 b	10
	High	5.1 b	3.0 b	2.44 c	3
Shell's Lick (ponderosa pine)	Slight	15.0 a	5.4 a	6.19 a	52
	Moderate	12.4 b	4.9 b	5.34 b	21
	High	11.7 b	4.3 c	4.85 b	9
Dawson Creek (lodgepole pine)	Slight	11.7 a	5.4 a	6.44 a	13
	Moderate	9.7 b	5.1 a	5.80 a	5
	High	9.9 b	5.1 a	5.86 a	13

Table 2—The effects of soil penetration resistance on diameter at breast height (DBH), radial growth (RG), and tree height. Values are means for each penetration resistance class; means with different letters are significantly different using a least significant difference test at the 10 percent level

Site	Penetration class	DBH	RG	Height	Plots
		cm	*cm/10 yr*	*m*	*Number*
Deadwood (lodgepole pine)	Slight	7.1 a	4.3 a	3.97 a	10
	Moderate	6.1 b	3.4 b	3.84 a	13
	High	5.3 b	3.2 b	2.96 b	6
Shell's Lick (ponderosa pine)	Slight	13.7 ab	4.9 a	5.73 a	32
	Moderate	14.5 b	5.1 a	6.10 a	40
	High	12.4 a	5.1 a	4.94 b	10
Dawson Creek (lodgepole pine)	Slight	13.0 a	5.7 a	6.77 a	5
	Moderate	10.4 b	5.0 a	6.01 a	20
	High	10.2 b	5.2 a	5.73 a	6

Table 3—Bulk density (0 to 17 cm) values at each study site. Mean (u) is the mean of all undisturbed plots and represents natural surface bulk density; mean (d) is the mean value for plots disturbed by logging

Site	Mean (u)	Standard deviation	Mean (d)	Standard deviation
	- - - - - - - - - - - - - -	*Mg/m³*	- - - - - - - - - - - - - -	
Deadwood	0.90	0.13	1.30	0.19
Shell's Lick	.82	.05	.94	.11
Dawson Creek	.76	.10	1.15	.16

insufficient in thickness to cause significant growth declines with increasing bulk density, may have been present. There were no growth declines attributable to compaction (penetration or bulk density increase) at Shell's Lick except for a significant height loss associated with the high penetration resistance class.

At Dawson Creek there were significant increases in bulk density from 0.76 to 1.15 Mg/m^3, particularly in skid trails. D.b.h. declines were significantly correlated with penetration resistance at Dawson Creek (table 2) but not radial growth or height declines. D.b.h. declines did not test significant with increased bulk density at $\alpha = 0.1$, but did test significant at $\alpha = 0.2$. Although the bulk density increases expressed as a percentage over natural were greater at Dawson Creek than at Deadwood (table 3), mean bulk density of disturbed plots was greater at Deadwood, and this suggests that a threshold value is exceeded before growth declines result. These overall higher densities may be the reason why declines in all growth factors with increasing bulk density were found at Deadwood but not the other two sites.

An analysis of covariance on the data sets from all three sites was run with bulk density as a continuous covariate along with the three penetration resistance classes to test for interactions. Again, tests of bulk density effects on growth within penetration resistance classes at Shell's Lick and Dawson Creek showed that the differences among the means were not significant. When the effect of bulk density was removed from the model at Deadwood, penetration resistance classes exhibited no significant effect on growth. Note that penetration resistance had a significant effect on all three growth factors at Deadwood in the one-way analysis of variance. In addition, adjusted means for growth response for each penetration resistance class in the covariance analysis were similar to means in the one-way analysis. This suggests that density and penetration resistance tests may be measuring the same effect on growth factors, and one might select either for soil monitoring purposes.

DISCUSSION

Productivity losses resulting from soil disturbance are difficult to predict. Actual losses depend on the percentage of area impacted, associated growth decline for a given level of impact, and the rate of recovery. Percentage of area impacted is relatively easy to estimate (and manage), and our results give an estimate of growth decline for a single point in the stand life by disturbance level. For example, moderate soil displacement at Shell's Lick resulted in mean declines of 17 percent, 9 percent, and 14 percent in d.b.h., radial growth, and height, respectively, compared to undisturbed soils. High soil displacement resulted in an additional decline of 12 percent in radial growth. Based on parabaloid bole volume estimates, current volume reductions of 40 percent and 53 percent are realized from the growth reductions associated with moderate and high displacement of soils at Shell's Lick. Similarly, calculations of volume losses associated with penetration resistance at the Deadwood site suggest a current volume loss of 44 percent on those sites placed in the high penetration resistance class. At the Deadwood site calculations could be made for volume losses associated with increased bulk densities because significant growth declines were observed.

Recovery rates following soil disturbance are a currently unknown factor, and this uncertainty makes any estimates of increases in length of rotation or volume loss at rotation for the stand highly speculative. However, we feel that lateral soil displacement effects result in a long-term impact that is not readily reversed. Recently published data by Froehlich and others (1985) suggest that increased soil densities from compaction during logging activity might not recover for longer than 25 years except near the surface in granitic soils, and may take longer than 40 years in the 15- to 30-cm depth zone in soils formed from volcanic parent materials in central Idaho. Soil recovery from increased resistance to penetration would likely parallel bulk density declines, although this is not certain. No data are available on recovery rates from soil displacement that can be logically related to tree growth response. Others have used such factors as long-term estimates of soil formation rates to define soil loss tolerance for farmland agriculture. However, the intensities of various soil-forming factors on forested slopes are different and inadequately defined to estimate recovery of biological productivity.

Although our data are not adequate to estimate the long-term productivity consequences of the observed growth losses in this study, we feel that the growth losses attributed to lateral displacement and compaction will either extend the length of time required to produce merchantable timber or result in volume losses at harvest.

CONCLUSIONS

The results of this study suggest that soil displacement and compaction from logging activities, brush disposal, and site preparation work can adversely affect growth of the regenerating stand. Significant (90 percent level) declines in one or more growth attributes were associated with increased penetration resistance and soil displacement at all three sites. Only one site, Deadwood, showed significant growth declines associated with increased soil bulk density (99 percent level). Our data are not adequate to predict productivity losses over a rotation. However, the growth declines observed in pole-sized trees are likely to result in extended rotations (assuming rotations are determined by culmination of mean annual growth) or reduced volumes even assuming immediate amelioration of the soil problems.

Several options are available to avoid or minimize productivity losses. Use of low ground pressure equipment, avoiding operations when the soil is wet, or logging over snow may avoid compaction effects altogether. Ripping has been used successfully to reverse compaction (Greacen and Sands 1980). Dedicated skid trails allow managers to control the percentage of area adversely impacted. Careful use of blades during slash piling or site preparation will reduce impacts of soil displacement.

Future studies are needed in the Northern Rocky Mountains to determine how long soil disturbance effects persist and the long-term effects of these disturbances on site productivity.

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INTERMOUNTAIN RESEARCH STATION

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